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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-79-0789-3

**MANUFACTURING METHODS AND TECHNOLOGY PROGRAM
FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE**

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**THIRD QUARTERLY PROGRESS REPORT
FOR PERIOD
JANUARY 1, 1980 - MARCH 31, 1980**

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MANUFACTURING METHODS AND TECHNOLOGY
PROGRAM FOR RUGGEDIZED TACTICAL
FIBER OPTIC CABLE

THIRD QUARTERLY PROGRESS REPORT

FOR THE PERIOD OF JANUARY 1980 - MARCH 1980

Contract No DAAK80-79-C-0789

Prepared for:

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- (a) Complete polyurethane jacket evaluation samples (four types, four manufacturers),
- b) Complete fungus testing,
- c) Select optimized polyurethane type,
- (d) Begin optimized cable fabrication for third engineering sample,
- (e) Deliver second engineering sample and test report (lay length and polyurethane evaluation samples,
- 2. Use of Facilities ;
 - (a) Achieve 75% of production rate on the high speed strander,
 - b) Install new Kevlar serving line, start setting up, and make operational,
 - c) Complete extruder set up and work toward 0.8 h/km rate ,
 - (d) Set up and make spooler operational, achieve 50% production rate,
 - (e) Assemble test stations and characterize,
- (3) Secondary Performance Milestones ,
 - a. Achieve 0.5 dB/km induced attenuation from cabling operation ,

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling manufacturing flow, and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

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MANUFACTURING METHODS AND TECHNOLOGY PROGRAM
FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

THIRD QUARTERLY PROGRESS REPORT

For the Period of January 1980 - March 1980

Object of Study:

To Establish an Automated Production Process for
Ruggedized Tactical Fiber Optic Cable

Contract No DAAK80-79-C-0789

Prepared by:

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ABSTRACT

This report covers the third quarter, January 1980 through March 1980, of the Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable. The scope of this quarter's effort, as reported herein, includes the following tasks and achievements:

1. Cable Process Optimization
 - a. Complete polyurethane jacket evaluation samples (four types, four manufacturers)
 - b. Complete fungus testing
 - c. Select optimized polyurethane type
 - d. Begin optimized cable fabrication for third engineering sample
 - e. Deliver second engineering sample and test report (lay length and polyurethane evaluation samples)
2. Use of Facilities
 - a. Achieve 75% of production rate on the high speed strander
 - b. Install new Kevlar serving line, start setting up, and make operational
 - c. Complete extruder set up and work toward 0.80 h/km rate
 - d. Set up and make spooler operational, achieve 50% production rate
 - e. Assemble test stations and characterize

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3. Secondary Performance Milestones -

- a. Achieve 0.5 dB/km induced attenuation from cabling operation

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling manufacturing flow and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

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PURPOSE

The purpose of this Manufacturing Methods and Technology (MM&T) Program is to establish automated production processes for Ruggedized Tactical Fiber Optic Cables in accordance with Specification MMT-789898 dated 2 February 1978, and ECIPPR No 15.

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GLOSSARY

Fused Coupler	- Optical coupler for power splitting formed by fusing two or more optical fibers
Injection Fiber	- Illuminated fiber used as a measurement light source
ITT EOPD	- ITT Electro-Optical Products Division
Lock-In Amplifier	- Amplifier used for precise instrumentation measurements in which offset drift is compensated by using a chopped source signal as a reference
NA	- Numerical aperture
PCS Fiber	- Plastic clad silica fiber
RTV	- Silicone buffer coating (room temperature vulcanizing)
PIXEL	- Picture element

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1.0 NARRATIVE AND DATA

The following information covers a physical description of the device (Appendix A), performance, effects of processes, and measurement techniques used on this program.

1.1 Device

The following paragraphs define the methods used to optimize the ruggedized tactical fiber optic cable, manufacturing processes, and measurement techniques.

1.1.1 Ruggedized Cable Design

The purpose of this program is to establish an automated production process for a ruggedized tactical fiber optic cable. Figure 1 shows the general cable configuration to be optimized on the program.

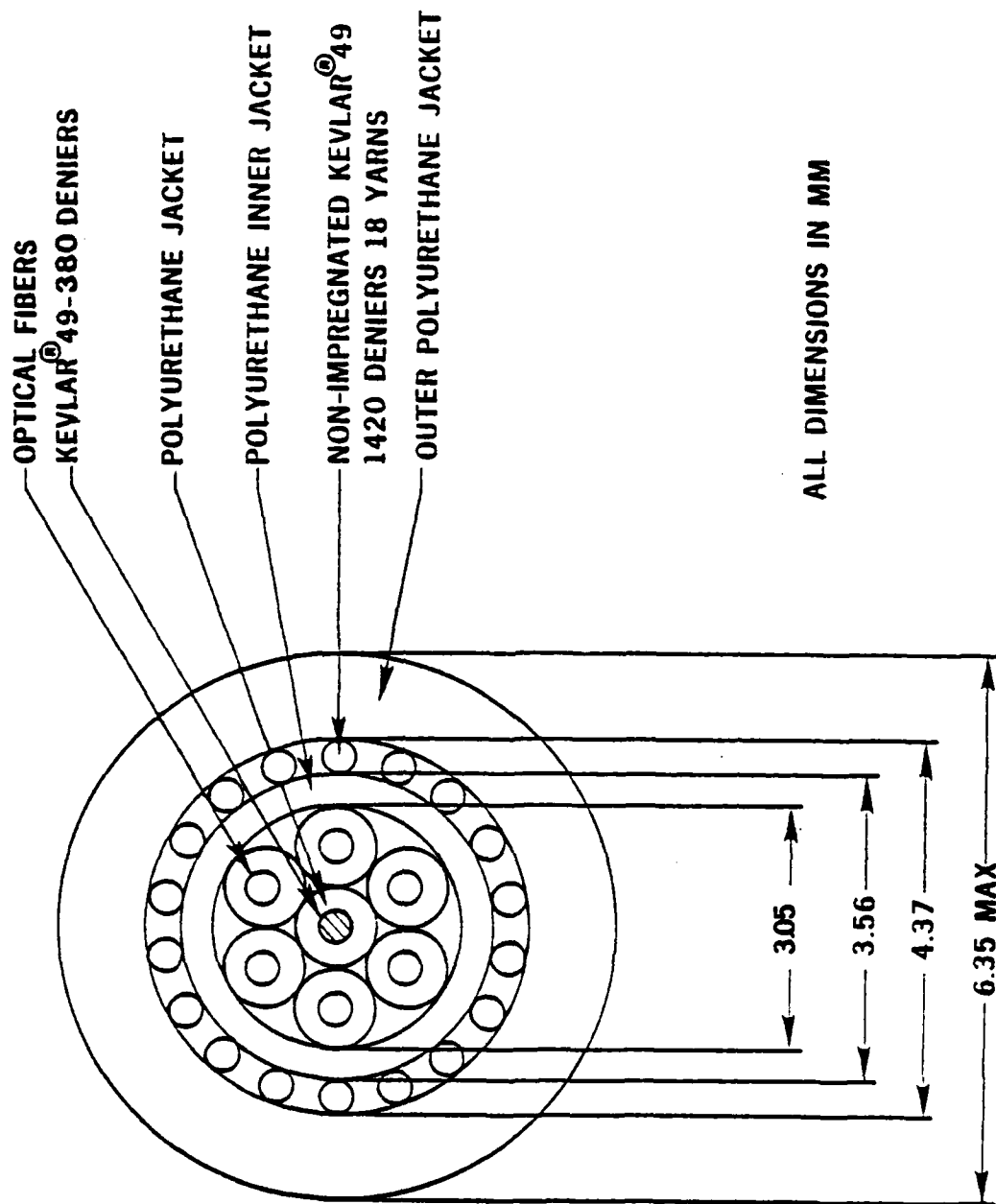
1.1.2 Polyurethane Jacket Optimization

The polyurethane material type was optimized by evaluating four different manufacturers of polyether grade urethanes.

1.1.3 Purpose of Phase III Polyurethane Optimization

The third group of samples in the MM&T engineering phase

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Figure 1. Basic MM&T Cable Design.

evaluates all four manufacturers of polyurethanes to select the most durable type for use in the MM&T final optimized engineering samples.

1.1.3.1 Phase III Optimization

Four cables have been constructed under this phase using the basic cable design of Figure 1 with the following jacket material variations:

- a. Design 1 - Uniroyal Roylar E9-B Polyurethane
- b. Design 2 - B. F. Goodrich 58300 Polyurethane
- c. Design 3 - Upjohn 2103-80 WC Polyurethane
- d. Design 4 - Mobay Texin 985A Polyurethane

1.1.3.2 Manufacturing Problems

All cables were constructed with only minor extrusion condition variations for each polyurethane type. The extrusion temperature was varied less than $\pm 5\%$ of the processing conditions for Roylar E9-B to optimize each polyurethane type. The polyurethanes evaluated in cable design 2, 3, and 4 demonstrated much higher adhesion to itself on the reel than does the standard Roylar E9-B evaluated in design 1.

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1.1.3.3 Phase III Conslusions and Recommendations

Detailed data from the Phase III optimization is contained in the second engineering sample test report. The data summary from the Phase III samples, located in Appendix B, was used to select an optimized polyurethane type based on environmental and mechanical performance. The method used to select the optimized polyurethane is illustrated in Table 1. The following conclusions were drawn:

- a. Impact resistance - Uniroyal Roylar E9-B and Mobay Texin 985A performed very well as possible jacketing materials.
- b. Polyurethane tackiness - Only cables extruded with Roylar E9-B exhibited a low adhesion to itself on the reel, making the manufacturing process less likely to cause fiber damage.

Based on the above results, Uniroyal Roylar E9-B is recommended as the optimized polyurethane type, with Mobay Texin 985A as a possible second source material.

1.2 Process, Equipment and Tooling

This section covers the manufacturing process, equipment used, and any necessary tooling.

1.2.1 Cable Manufacturing Process

This section describes each manufacturing station and its capabilities.

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Table 1. Summary of Data.

Test Performed	Design Number *			
	1	2	3	4
Impact	Very Good	Poor	Fair	Very Good
Twist	Excellent	Excellent	Excellent	Excellent
Bend	Excellent	Very Good	Very Good	Excellent
Tensile Load	Excellent	Excellent	Excellent	Excellent
Cold Bend	Excellent	Excellent	Excellent	Excellent
Fungus	Excellent	Excellent	Excellent	Excellent
Polyurethane Tackiness	Very Good	Fair	Poor	Poor
Cable Rating	33	26	26	29

*Design 1 - Uniroyal Roylar E9-B Polyurethane
 Design 2 - B. F. Goodrich 58300 Polyurethane
 Design 3 - Upjohn 2103-80WC Polyurethane
 Design 4 - Mobay Texin 985A Polyurethane

Excellent - 5
 Very Good - 4
 Good - 3
 Fair - 2
 Poor - 0

1.2.1.1 Fiber Rewind Station

This station (Figure 2, Operation E1) will be used to respool and inspect fibers in preparation for the subsequent stranding operation. The equipment consists of a rewinder, an optical lump detector to examine the fiber buffer jacket for any nonuniformities, and a constant-tension compensating payoff to eliminate any fiber breaks due to high tension levels.

This unit will allow fibers to be inspected for buffer jacket flaws optically at control tensions.

The Amacoil rewind station has constantly developed malfunctions. These malfunctions require a long time to repair because of foreign suppliers of parts. For these reasons, the unit is being returned to the manufacturer for adjustments or replacement. This will be scheduled so no program impact occurs.

1.2.1.2 Fiber Continuity Check Station

Before the fibers are stranded into a cable bundle it is essential that each fiber's continuity be tested and any

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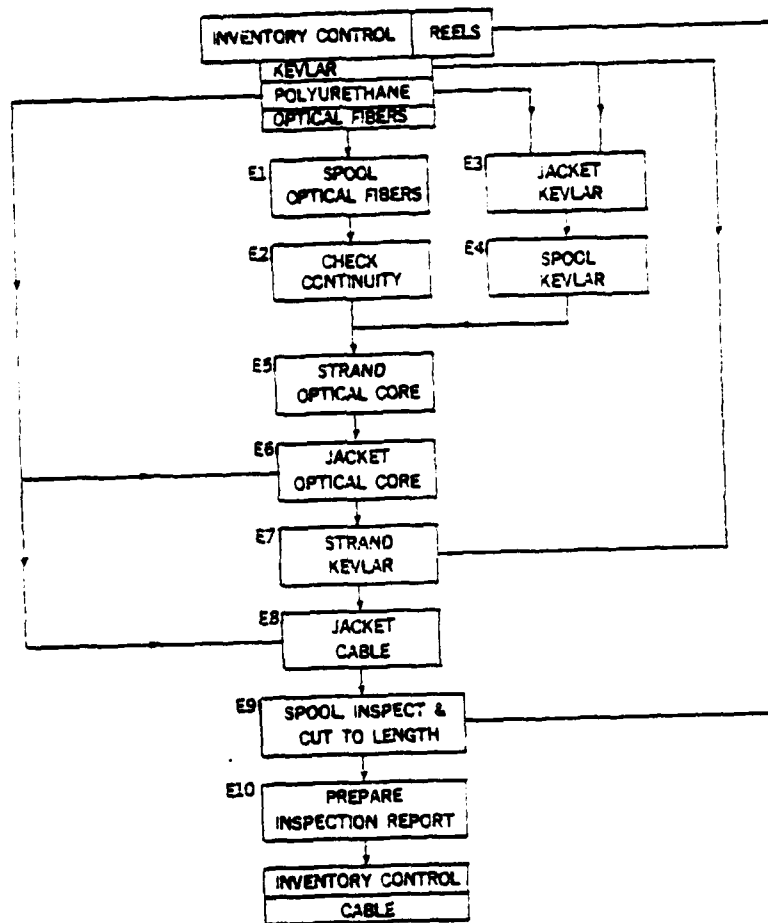


Figure 2. Cable Fabrication Flow Chart.

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broken fibers removed to ensure a high production yield. The unit used at this station (Figure 2, Operation E2) will include a large area light emitting diode (LED) and a large silicon detector. The LED and detector will be properly mounted for automatic axial alignment and quick operation to minimize the time required to examine each fiber for light transmission.

To complete this unit, minor modifications to existing equipment is all that will be required.

1.2.1.3 Kevlar Jacketing Station

The purpose of this station (Figure 2, Operation E3) is to overcoat a Kevlar 49-380 denier yarn with a polyurethane jacket which will be used as the central core for the optical bundle. The extruder to be used is a 1 in unit with the capacity of pressure extruding the polyurethane jacket at a current rate of 76 m/min.

This unit is an existing production station. An automatic diameter controlling process unit has been installed. This

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unit will detect the diameter of the core element being extruded and regulate the extruder rpm to provide a constant diameter over the length of a standard production run.

1.2.1.4 Respooling Station for Polyurethane Jacket Kevlar
This operation will be completed using the fiber rewind station equipment outlined in paragraph 1.2.1.1. The capacity of this unit is ample to complete both fiber rewind and respooling operations (Figure 2, Operation E4).

1.2.1.5 Optical Core Stranding Station

The purpose of this station (Figure 2, Operation E5) is to strand the six optical fibers helically around the Kevlar center core member. To do this operation, a high speed single twist closing unit equipped with a seven bay neutralizing unit will be used.

Fibers stranded on the second engineering samples and standard production cables indicate that there was a tension control problem causing high peak tensions and excessive

cable attenuation increases. The equipment has been modified and no further problems have developed on standard production cables running at 75% of production speed.

1.2.1.6 Optical Core Jacketing Station

This station is to be used to extrude the polyurethane jacket over the optical bundle. The extruder is a 1 1/2 inch extrusion line capable of extruding the above jacket at 68 m/min, well over the required MM&T rate of 20 m/min.

The new payoff unit has been installed and functions properly. This unit will handle the larger capacity spools needed to run long lengths (1 km) of cable.

1.2.1.7 Kevlar Stranding Station

The purpose of this station (Figure 2, Operation E7) is to strand 18 Kevlar strength members around the jacketed optical core. The modified yarn serving machine has been received, installed, and currently operational at 50% of production rate for the MM&T program.

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1.2.1.8 Final Jacketing Station

the 2-inch extrusion line (Figure 2, Operation E8) will be used to extrude the final jacket on the ruggedized cable. The extrusion line was used to extrude the final jacket at 42 m/min on the polyurethane evaluation samples in Phase III. This rate is double that required (0.8 h/km) on the MM&T program.

1.2.1.9 Final Cable Respooling Station

At this station (Figure 2, Operation E9) the cable will be spooled onto the shipping reel, inspected for visual defects, and cut into 1 km \pm 5 m lengths.

An Eaton-Dynamatic Multi-Trol system will be used to improve the payoff tension control. This unit provides a constant tension at all respooling speeds by regulating the payoff spool and braking functions.

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2.0 FIBER AND CABLE TEST STATIONS

In the third quarter, the major emphasis was on the assembly and characterization of the evaluation stations.

The modifications required to meet the contract objectives were made to the stations and tests were conducted to determine the test stations characteristics.

2.1 Fiber End Preparation Station

The modified barrel fixture of Figure 3 was ordered. During vendor fabrication however, a problem with precision drill availability necessitated a change to a precision jewel fiber aperture. The precision jewel fiber aperture units will be delivered in early April for characterization.

2.2 Pulse Dispersion Station

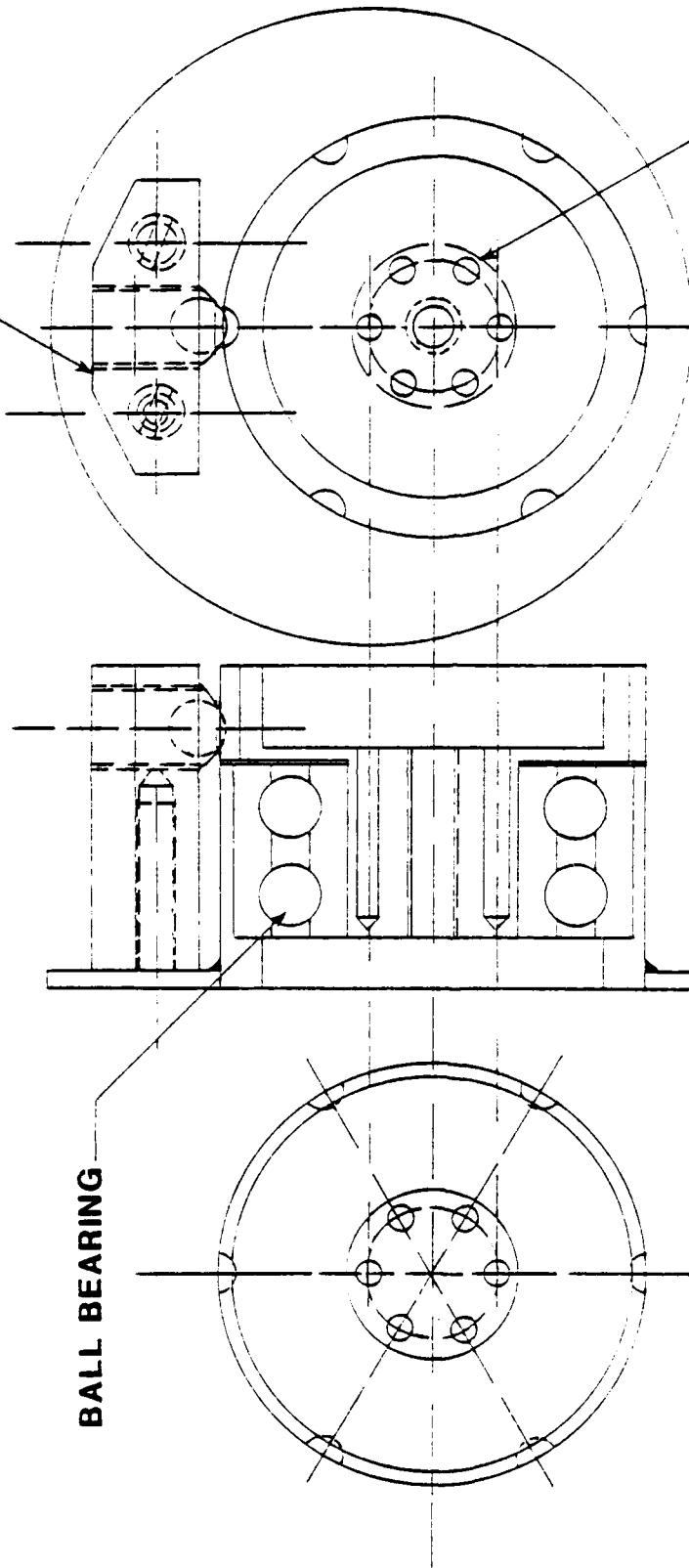
The second avalanche photodiode was added to the dispersion station of Figure 4. This addition facilitates continuous monitoring of the input pulse condition during a measurement without disturbing the fiber under test. Of a number of detectors which were tested for similarity of time response referenced to the output detector, a C30921E cane-coupled APD was selected. The test results before and after pigtailling the APD are shown in Table 2. As indicated, the pulsewidth

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SPRING LOADED
PLUNGER

FIBER END
POSITIONING JEWELS

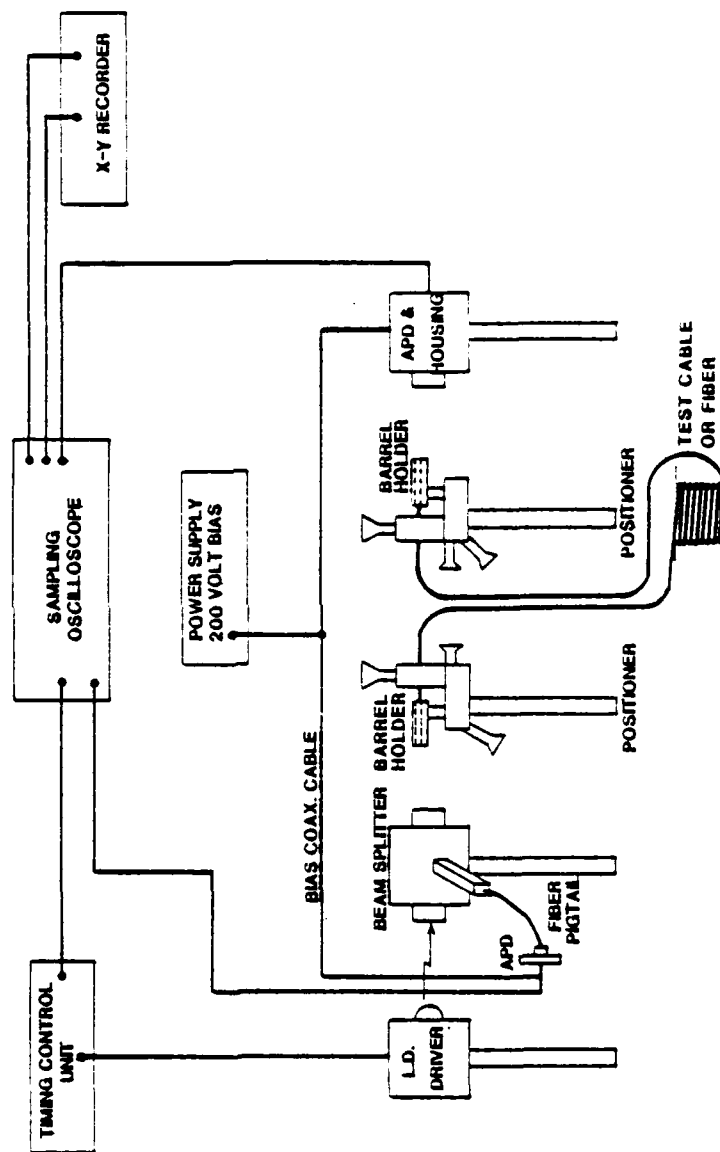
BALL BEARING



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MODIFIED FIBER POSITIONING FIXTURE DESIGN

Figure 3



DISPERSION TEST MEASUREMENT STATION

Figure 4.

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Table 2. Dispersion Station Test Results

A. Monitoring APD Tests

	50% Pulse Width	
	<u>Before Y-596 Pigtailed</u>	<u>After Y-596 Pigtailed</u>
Output Detector	.54	.54
Monitor APD Y-596	.52	.58

B. Monitoring Tests

<u>Laser Current</u>	<u>Ratio of Pulse Widths (FWHM)</u>	
	<u>Test 1</u>	<u>Test 2</u>
V Threshold + .6 V	.87	.92
V Threshold + .8 V	.92	.94
V Threshold + 1.0 V	.94	.94
V Threshold + 1.2 V	.94	.94
V Threshold + 1.4 V	1.00	1.30

C. Dispersion Reproducibility

<u>Test Number</u>	<u>Dispersion (ns/km)</u>
1	.43
2	.38
3	.40
	<u>.40 Avg. ± 0.03 ns/km</u>

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increased. This effect is believed due to coupling differences in the initial tests due to packaging differences.

To demonstrate the capability of the monitor APD to track the input pulse, tests were conducted comparing the beam-splitter pulse with the pulse from a one meter length of graded index fiber at various drive levels. The results, shown in Table 2, show good agreement near the usual drive condition of V threshold +1 V. At lower and higher drive levels, the agreement is much less reproducible due to instabilities in the laser output. Additional testing will be conducted to determine stability and deviation.

Three dispersion measurements were performed on a 1200 m graded index fiber to gauge reproducibility. The results shown in Table 2 indicate acceptable variations of ± 7 per cent.

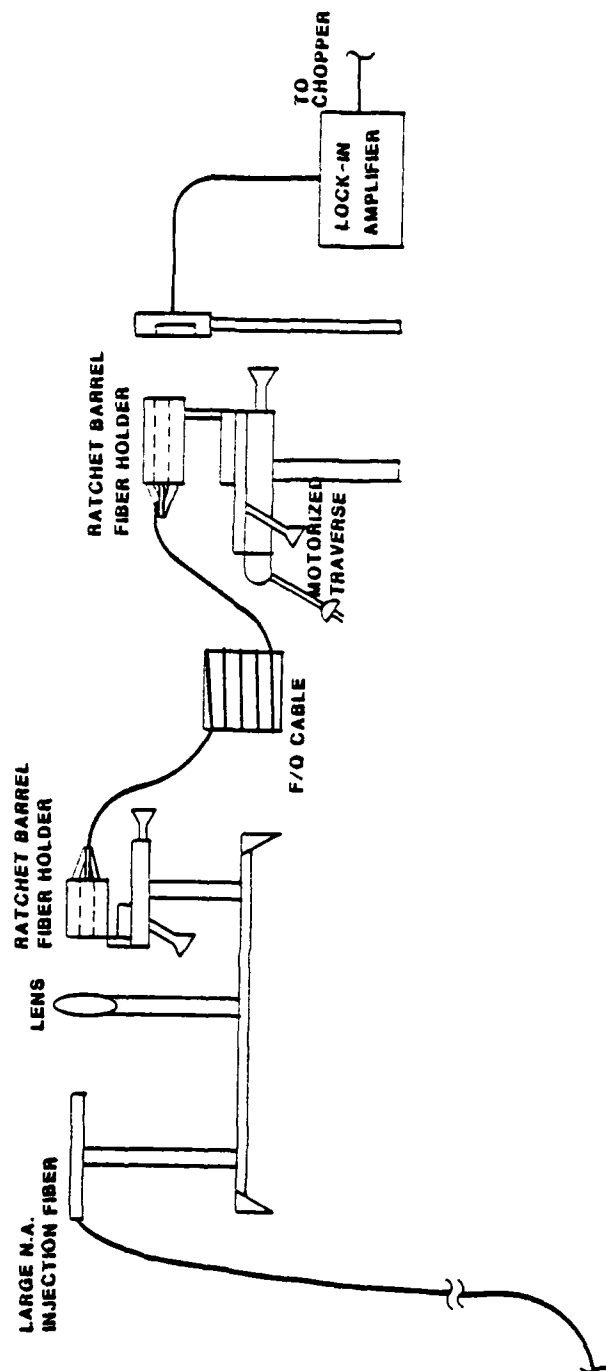
2.3 NA Test Station

The 90% power NA station was reconfigured for faster operation. The new station is shown in Figure 5.

The motorized micropositioner, which moved at a speed of 0.14 mm/sec was replaced by a motorized traverse which moves at speeds in excess of 15 mm/sec.

Position of the fiber end is monitored by a

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90% POWER N.A. MEASUREMENT STATION

Figure 5.

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dual caliper graduated to .001". Tests were conducted to determine the reproducibility of the station. The data, shown in Table 3 indicates a variation of $\pm 0.4\%$ worst case for the same injection conditions on a short length test. The long length measurement variation was $\pm 1.9\%$ when new detection ends were made with each measurement.

2.4 Attenuation Measurement Station

The attenuation station of Figure 6 was assembled. The station utilizes GE detectors to monitor both the input and output power over the wavelength region of interest (0.82 to 1.20 μm).

A large area output detector was tested and proved excessively noisy. A smaller area device was then substituted, which required output optics.

A number of tests have been initiated to determine measurement reproducibility. Several problems related to the stability of the lock-in amplifiers have impacted the completion of these tests.

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Table 3. 90% Power NA Characterization

A. Short Length - Repeated with same injection conditions

1. .2125
2. .2131
3. .2127
4. .2121
5. .2113

Average .2122 - Max +0.4%, Min -0.4%

Sample = 3 m of fiber (M-3) graded index

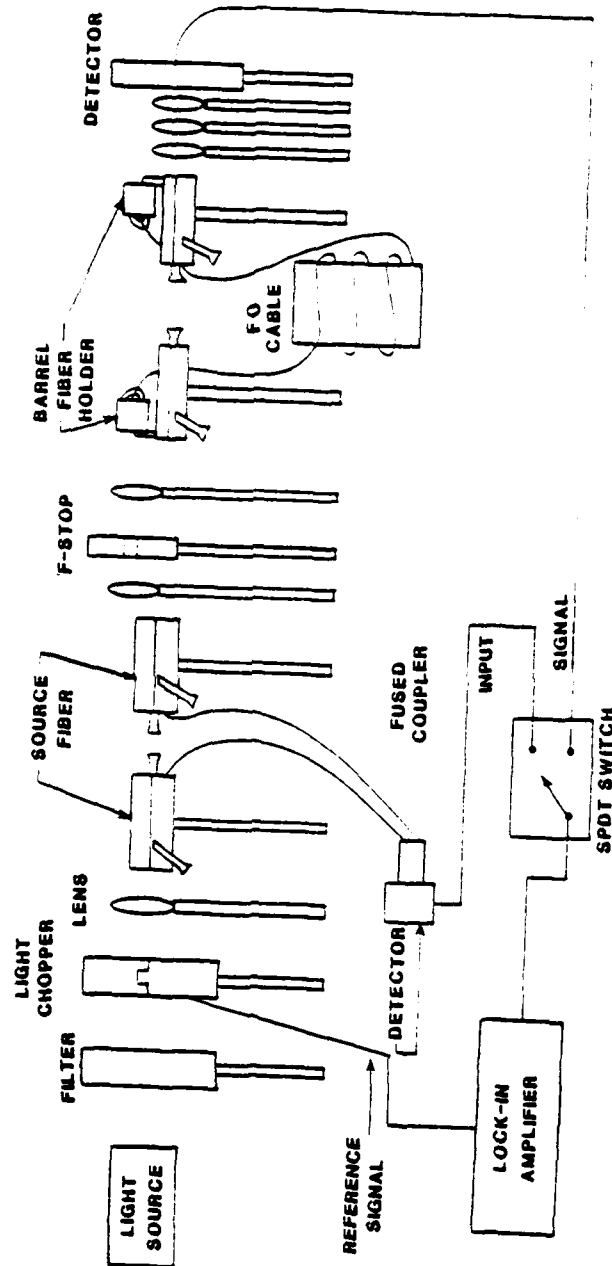
B. Full Length - New Detection Ends

1. .2026
2. .2028
3. .1997
4. .2072
5. .2048

Average .2034 - Max +1.9%, Min -1.8%

Sample = 1200 m of fiber (M-3) graded index

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ATTENUATION MEASUREMENT STATION

Figure 6.

10. 12556

3.0 FLOW CHART OF MANUFACTURING PROCESS

Figures 2 and 7 show the flow of materials and product through the proposed pilot line production facility. Each station is identified with a letter/number code.

Plans are to produce cables in lengths of 4 km, thus reducing setup time at each station considerably. The expected result of the above is to increase efficiency so that the overall production yield will be 87%. This yield will be evaluated after the final optimized engineering samples are constructed in a 3.6 km continuous length.

Table 4 lists all operations with the expected production rate at each work station. (Major work stations have been discussed in paragraph 1.2.) At this time in the program there is no obvious reason to believe that the proposed production rates cannot be met or exceeded.

3.1 Data and Analysis

The data summary for the second engineering samples is located in Appendix B along with the analysis as indicated in the second test report.

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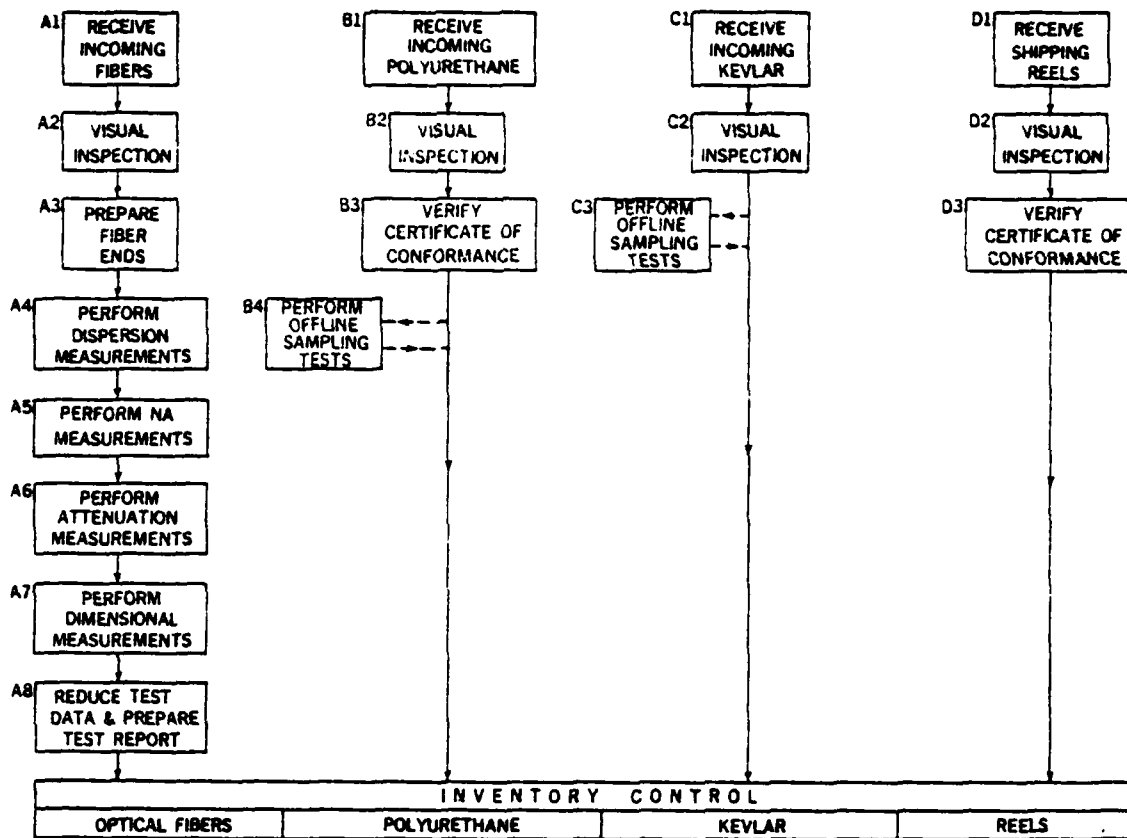


Figure 7. Incoming Inspection and Quality Control Flow Chart.

Table 4. Production Rate by Operation.

Operation	Operation Description	Set-up Time hrs/km	Run Time hrs/km	Total Time hrs/km Cable
A01	Receive Incoming Fibers	-	-	-
A02	Visual Inspection	0.020	-	0.184
A03	Prepare Fiber Ends	0.020	-	0.184
A04	Perform Dispersion Measurement	0.050	-	0.459
A05	Perform NA Measurement	0.050	-	0.459
A06	Perform Loss Measurement	0.050	-	0.459
A07	Perform Dimensional Measurement	0.050	-	0.459
A08	Reduce Test Data and Prepare Test Report	0.080	-	0.736
B01	Receive Incoming Polyurethane	-	-	-
B02	Visual Inspection	0.020	-	0.026
B03	Verify Certificate of Conformance	0.010	-	0.013
B04	Offline Sampling Tests	-	-	-
C01	Receive Incoming KEVLAR	-	-	-
C02	Visual Inspection	0.020	-	0.026
C03	Offline Sampling Tests	-	-	-
D01	Receive Shipping Reels	-	-	-
D02	Visual Inspection	0.050	-	0.056
D03	Verify Certificate of Conformance	0.050	-	0.056
E01	Spool Optical Fibers	0.030	0.090	0.327
E02	Check Continuity	0.050	-	0.344
E03	Jacket KEVLAR	0.130	0.370	0.574
E04	Spool KEVLAR	0.030	0.090	0.138
E05	Strand Optical Core	0.060	0.310	1.000
E06	Jacket Optical Core	0.260	0.540	0.913
E07	Strand KEVLAR	0.200	0.410	0.700
E08	Jacket Cable	0.230	0.157	0.918
E09	Spool, Inspect & Cut to Length	0.170	0.630	0.913
E10	Prepare Inspection Report	0.500	-	0.356
F01	Prepare Fiber & Cable Ends	0.750	-	0.833
F02	Perform Dispersion Measurement	0.900	-	0.918
F03	Perform NA Measurement	0.670	-	0.744
F04	Perform Loss Measurement	0.300	-	0.913
F05	Perform Dimensional Measurement	0.900	-	0.913
F06	Prepare Cable Ends for Shipping	0.130	-	0.202
F07	Reduce Test Data and Prepare Test Report	0.660	-	0.734
F08	Offline Sampling Tests	-	-	-
Total Production Time				15.277

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3.2 Results

Based on the data reported in Appendix B, Uniroyal Roylar E9-B was selected for the polyurethane jacket material on the final optimized engineering samples. The Mobay Texin 985A performed equally well on the environmental and mechanical testing, but the cable jacket adheres to itself on the reel severely making the manufacturing operations more difficult. Mobay Texin 985A will be further considered as a possible second source for this MM&T program.

Roanoke, Virginia

4.0 CONCLUSIONS

The data from Phase I samples has resulted in the 1.02 mm Hytrel 7246 fibers being selected because of best overall performance. This fiber will be used in all further cable optimization processes.

The data from Phase II samples shows excellent optical and mechanical performance. The 3.0 in lay length was chosen for all further cable optimization processes because of an increased cable production rate over shorter lay lengths, without any penalty in performance.

Tubing extrusion was selected over pressure extrusion for the following reasons:

- a. Higher production speed
- b. Better concentricity
- c. Greater production yield
- d. Equal optical and mechanical performance
- e. Less material scrap

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The polyurethane selection process in Phase III samples has resulted in Uniroyal Roylar E9-B indicating the best overall performance as noted in Section 1.1.5.2 and will be used in the final optimized engineering samples.

No problems have been identified in the equipment or measuring station design which will adversely affect the delivery schedules or performance milestones. All milestones have been achieved on or ahead of schedule.

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5.0 PROGRAM FOR NEXT INTERVAL

Milestone achievements for the next quarterly interval are listed below:

- a. Construct optimized engineering samples
- b. Complete optical and mechanical testing of final optimized engineering samples
- c. Deliver third engineering samples and test report (final optimized engineering samples)
- d. Receive DR-5 reels for confirmatory samples
- e. Achieve 75% of production rate on the high speed strander
- f. Achieve 50% of production rate on the Kevlar serving line
- g. Optimize 2 in extruder performance
- h. Achieve 75% of production rate on fiber respooling and inspection line
- i. Complete preliminary assembly of measurement test stations, run time study, and make final modifications
- j. Achieve 0.35 dB/km induced attenuation from cabling operation
- k. Evaluate yield to achieve 50% goal

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6.0 PUBLICATION AND REPORTS

There have been no publications, conferences and/or talks made during the period on or associated with the research, study, or development under contract.

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7.0 IDENTIFICATION OF PERSONNEL

Table 5 is a list of the names of personnel working on the program who are considered professional and skilled technical personnel. The task performed and the manhours of work performed by each during the interval of the report are given.

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Table 5. Personnel Working on the MM&T Program

<u>Name</u>	<u>Task</u>	<u>Manhours Expended</u>
R. Hoss	Program Management	16
*J. Smith	Cable Production Management	22
R. Thompson	Technical and Administrative	33
R. Kopstein	Project Engineer	96
S. Mahurin	Measurements Supervision and Project Engineering	24
*H. Heinzer	Measurements Engineering	47

*Due to a change in the ITT EOPD organization, J. C. Smith is responsible for Cable R&D production management and H. Heinzer has been assigned responsibility for measurements engineering.

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BIOGRAPHICAL INFORMATION**NAME:** Hans E. Heinzer**POSITION:** Senior Engineer**EDUCATION:**

Mr. Heinzer was awarded a degree comparable to a BS in Electrical Engineering from the Cologne Chamber of Commerce, Cologne, Germany, in 1959.

EXPERIENCE:

Mr. Heinzer joined ITT Electro-Optical Products Division in May, 1978, after seven years at ITT Cable-Hydrospace Division (CHD) in San Diego, California. As Senior Engineer in the Fiber Optics Laboratory, he is presently working on special projects relating to optical fiber cables, terminations and undersea systems.

RESEARCH AND DEVELOPMENT

While associated with ITT CHD as a Transmission Engineer, Mr. Heinzer was engaged in the development of an underwater fiber optic link. He also participated in the design of hardware for underwater repeater housing and bulkhead fiber penetrators and prepared manufacturing documentation. In addition, he participated in a fiber optic repeater study. While under assignment as Deputy Program Manager of the Systems Group, Mr. Heinzer participated in overall system implementation for a \$5.5 million sea cable system in the China Sea. In this capacity he performed repeater testing and evaluation, survey, program control and logistics, and system documentation.

Prior to joining ITT CHD, Mr. Heinzer was associated with U.S. Underseas Cable Corporation in Washington, D.C., for five years. His research and development work there concerned envelope delay distortion equalization for wideband communications system from 1969 to 1970. As Senior Test and Equipment Engineer with responsibility for the Electronic Laboratory, Mr. Heinzer performed measurement and testing on carrier frequency equipment, equalizers and associated circuits.

From 1953 to 1966 Mr. Heinzer was an Electronic Technician at Felten & Guilleaume Carlswerk A.G. in Cologne. There he took part in the development of the first bidirectional underwater repeater. He made major contributions to the design and manufacture of a line of equalizers designed for shipboard or in-the-field assembly. He also participated in the implementation of 16 sea cable systems totalling 6871 nautical miles.

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BIOGRAPHICAL INFORMATION
H. E. Heinzer
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GOVERNMENT

From 1963 to 1967 Mr. Heinzer participated in building, laying and installation of 10 submarine cable systems totalling 4137 miles for the U.S. Air Force.

ADMINISTRATIVE

Mr. Heinzer was supervisor of the equalizer assembly white (clean) room on board the cable ship "Neptun" while associated with U.S. Underseas Cable Corporation. At Felten and Guilleaume Carlswerk A.G. he was supervisor of design and drafting and of quality control and test programs.

MANUFACTURING

Mr. Heinzer participated in the manufacture of underwater repeaters and equalizers and terminal equipment for telecommunication systems.

TECHNICAL

Mr. Heinzer's technical expertise includes the design of printed circuit boards and the packaging of electronic equipment (filters, equalizers, and underwater repeaters).

ORGANIZATIONS:

Mr. Heinzer is a member of IEEE.

PATENTS:

1. Submarine Housing for Submarine Cable System Repeater Components or the Like (No 4,172,212).
2. Fiber Optic Electromechanical Submarine Cable Termination, with O. R. Reh. (Case No. A-1592).

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APPENDIX A

PHASE II AND III OPTIMIZATION RESULTS

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A1.0 NARRATIVE AND DATA

The following information covers a physical description of the device, performance, effects of processes, and measurement techniques used on this program.

A1.1 Device

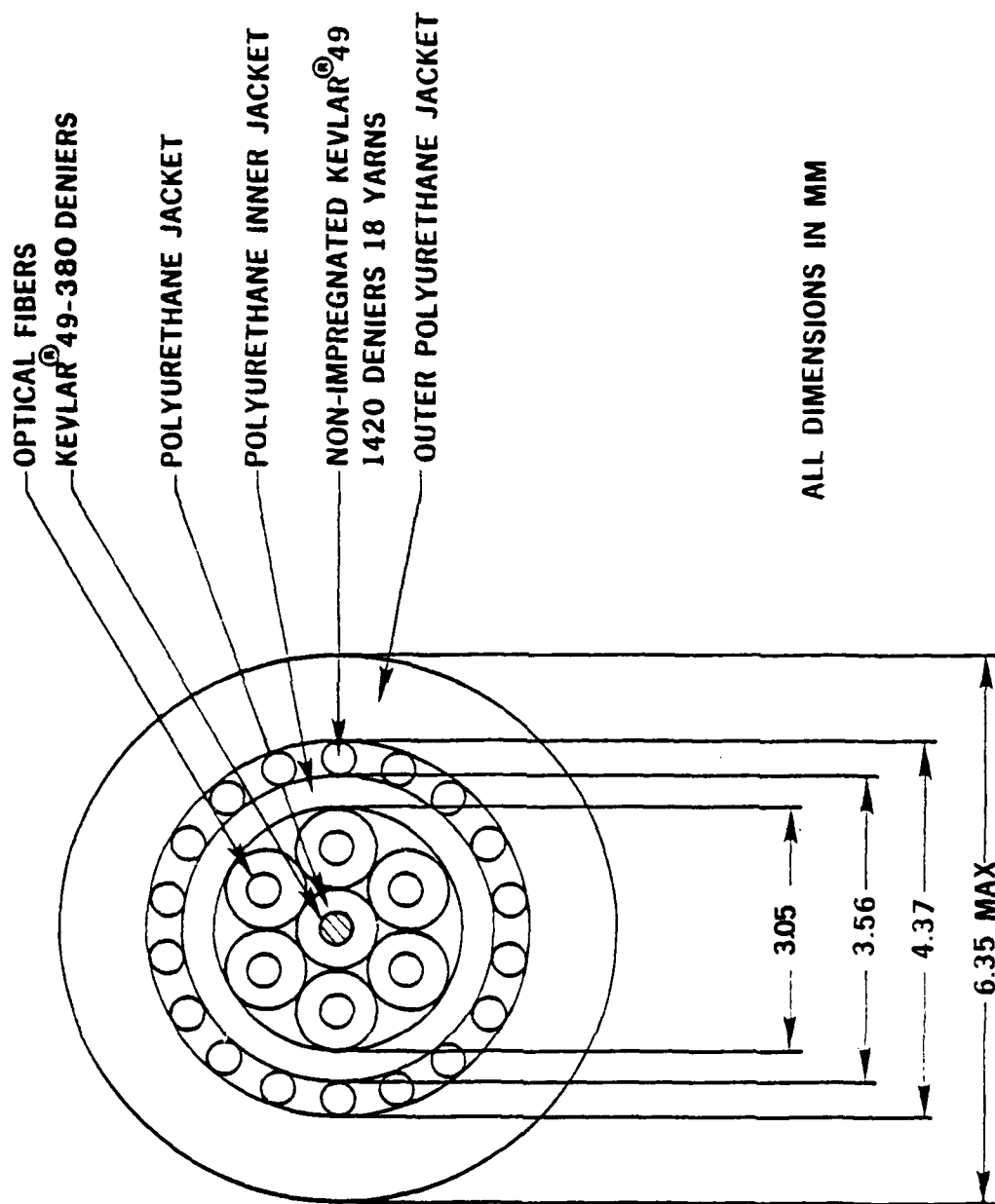
The following paragraphs define the methods used to optimize the ruggedized tactical fiber optic cable, manufacturing processes, and measurement techniques.

A1.1.1 Ruggedized Cable Design

The purpose of this program is to establish an automated production process for a ruggedized tactical fiber optic cable. Figure 1 shows the general cable configuration to be optimized on the program.

The light transmitting elements of the optical cable are the optical fibers consisting of a glass core and glass cladding. To preserve the mechanical strength of the glass fibers, they are coated with plastic buffers, the buffer being a solid plastic coating surrounding the optical fiber.

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302 10757

Figure A.1 Basic MM&T Cable Design.

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The graded-index optical fibers are to meet the following specifications at 0.82 μm wavelength after proof loading at 100,000 psi:

- | | |
|--------------------------------------|-------------------------------------|
| a. Fiber core | $\geq 50 \mu\text{m}$ |
| b. Fiber od | $125 \mu\text{m} \pm 6 \mu\text{m}$ |
| c. Attenuation | $\leq 5.0 \text{ dB/km}$ |
| d. Dispersion | $\leq 2.0 \text{ ns/km}$ |
| e. Numerical aperture
(90% power) | ≥ 0.20 |

A1.1.1.1 Primary Buffer

A room temperature vulcanizing (RTV) silicone protective coating, Dow Corning Sylguard [®] 184, is applied by dip coating to a finished diameter of 300 μm immediately after drawing. This protective coating guards the fibers from any initial handling or foreign substances that may damage or reduce the quality of the product and is compatible with the buffering materials.

A1.1.1.2 Secondary Buffer

All fibers have a Hytrel [®] 7246 buffer layer for additional protection. This layer is extruded to a finished diameter of 0.5 mm. An additional layer is extruded to 1.0 mm to provide the optimum mechanical and environmental performance. The "1" extruder is used for this operation.

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Hytrel[®] has a very low expansion/contraction coefficient, thereby improving the high/low temperature performance.

Al.1.1.1.3 Center Filler

The center filler shall be a Kevlar[®] 49 (380 denier) coated with polyurethane (Roylar[®] E-80) to a diameter of 1.0 mm. The center filler provides a cushioning to improve impact resistance.

Al.1.1.1.4 Polyurethane Inner Jacket

The polyurethane inner jacket is extruded after the cabling operation. The polyurethane used is a polyether based compound. It is chosen because of its extreme toughness, abrasion resistance, low temperature flexibility, resistance to hydrolysis, fungus resistance, and excellent stability to atmospheric conditions. This jacket supplies support for the fiber making up the cable core and provides a buffer layer between the fiber and Kevlar[®] reducing abrasion.

Al.1.1.1.5 Kevlar[®] Strength Member

Kevlar[®] 49 has been chosen as the strength member for this application because of its strength versus weight and durability. A total of 18 yarns (1420 denier) is applied

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helically with a 4.0 in lay length. The lay length was selected to be greater than that of the fibers to ensure that the Kevlar[®] takes the tensile load. The strength member will provide 400 lb tensile strength at 1% elongation. One percent elongation is the 100 kpsi fiber proof test point.

A1.1.1.6 Polyurethane Outer Jacket

The outer jacket material is identical to the inner jacket specified in Section A1.1.1.4.

A1.1.2 Optimization Process

The basic fiber optic cable will be optimized in four specific areas or phases. The three sets of engineering samples will be selected from this four-phase optimization process.

A1.1.2.1 Fiber Buffer Optimization (Phase I)

Three buffered fiber diameters of 0.94 mm, 1.02 mm, and 1.14 mm with Hytrel[®] 7246 were evaluated. Also, fibers were evaluated at 1.0 mm with Hytrel[®] 4056, Hytrel[®] 5556, and polyurethane Roylar[®] E-80. This phase is completed and cable samples from this phase were shipped as the first set of engineering samples.

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A1.1.2.2 Lay Length Evaluation (Phase II)

Cables were evaluated with fiber lay lengths of 2.0 in, 2.5 in, and 3.0 in. It is felt that lay lengths shorter than 2.0 in would cause induced microbending losses and lay lengths greater than 3.0 in would cause additional tensile load stresses along with high bending stresses.

A1.1.2.3 Pressure Versus Tubing Inner Jacket

The inner jacket was optimized by evaluating pressure versus tubing extrusion process.

A1.1.2.4 Outer Jacket

The polyurethane was optimized by evaluating four different manufacturers of polyether grade urethanes.

A1.1.3 Purpose of Phase I Optimization

Phase I of the MM&T program was designed to evaluate the effects of buffered fiber diameter and material type and hardness on the cable performance as follows:

- a. Buffered fiber diameter, Hytrel[®] 7246 (0.94 mm, 1.02 mm, 1.14 mm)
- b. Hytrel[®] hardness effects (4056, 5556, 7246)
- c. Material comparison (Hytrel[®] versus polyurethane)

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A1.1.4 Purpose of Phase II Optimization

Phase II of the MM&T program optimized the fiber lay length (2.0 in, 2.5 in, 3.0 in).

A1.1.4.1 Phase II Optimization

This optimization evaluated the cabled fiber lay length. Three cables have been constructed using the high speed strander at 50% of production rate under this phase II program following the basic cable design of Figure 1 with 1.02 mm Hytrel[®] 7246 fibers and the following variations:

- a. Design no 1 - 2.0 in lay length
- b. Design no 2 - 2.5 in lay length
- c. Design no 3 - 3.0 in lay length

A1.1.4.2 Manufacturing Problems

All cables were constructed without any problems; therefore, the lay length of the cabled optical fibers does not affect the manufacturing difficulty but does have a direct relationship to the manufacturing rate. It was decided at the onset of this phase to evaluate tubing versus pressure extrusion of the cable core in the event that the cable

could not pass the impact testing requirement. Tubing extrusion was selected over pressure extrusion without further engineering samples because the fibers already withstand the impact test and pressure extrusion would only improve impact performance but would have the following disadvantages:

- a. Lower production speed
- b. Poor concentricity
- c. Lower production yield
- d. Equal optical and mechanical performance
- e. More material scrap

Construction of engineering samples to evaluate pressure versus tubing performance was not a requirement in the MMGT program.

A1.1.4.3 Phase II Conclusions and Recommendations

The data from the phase II samples (see Tables 2 and 3) was used to select the optimized lay length from the optical and mechanical results. All three cables had excellent optical results. One of the fibers was broken in the 2.0 in lay length cable because of stepper motor problems with the high speed strander. The motor was replaced and no further problems have developed.

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Table A.2 Attenuation Data.

Fiber Ident	Design No 1			Design No 2			Design No 3		
	2.0" Lay Length			2.5" Lay Length			3.0" Lay Length		
	Before	After	Δ	Before	After	Δ	Before	After	Δ
1. Red	4.20	4.16	-0.04	3.95	3.65	-0.30	4.12	4.15	+0.03
2. White	3.74	**	**	3.58	3.67	+0.09	3.52	4.01	+0.49
3. Blue	3.79	3.99	+0.20	3.87	3.85	-0.04	4.16	5.55	+1.39
4. White	3.76	4.31	+0.55	3.70	3.23	-0.47	3.43	3.60	+0.17
5. White	3.81	3.56	-0.25	3.89	3.63	-0.26	3.48	3.55	+0.07
6. White	3.71	3.86	+0.15	3.54	3.31	-0.23	3.96	3.32	-0.64
Avg.	3.85	3.98	+0.13	Avg. 3.76	3.55	-0.21	Avg. 3.78	4.03	+0.25

*Attenuation measured at 0.82 μ m wavelength and 0.089 injection NA

**Fiber broke on high speed strander when bearings of the stepper motor failed.

Table A.3 Mechanical Testing.*

	Design No 1 2" Lay Length	Design No 2 2.5" Lay Length	Design No 3 3.0" Lay Length
Impact Resistance			
Total fibers	36	36	36
Failures	1	0	0
Percent surviving fibers	97.2	100.0	100.0
Twist Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Bend Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Tensile Load Test			
Total fibers	6	6	6
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0

*All testing was conducted at room temperature

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The mechanical testing data showed excellent results also with only one fiber failure on the 2.0 in lay length cable during the room temperature impact testing.

A 3.0 in lay length was selected for Phase III (polyurethane evaluation) based on the test results and because an increase in stranding rate can be realized over the shorter lay lengths. Stranding speed is a direct function of lay length. Further information was included in the test report for the second engineering samples.

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APPENDIX B
PHASE III OPTIMIZATION RESULTS

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B1.0 TEST RESULTS ON PHASE II

All data is summarized below for the second set of engineering samples.

B1.1 Attenuation Measurement Results

The attenuation was measured on spools with a 6" drum prior to cabling and after the cables were completed. The results of the data are summarized by the maximum, minimum, and average values for the six designs as noted in Table B-1.

The results indicate that changing the lay length from 5.1 cm (2.0") to 7.6 cm (3.0") does not affect the attenuation parameter. The after cabling data for the polyurethane evaluation samples showed erratic results because of tension control instability in the high speed strander. This problem has since been corrected.

B1.2 Pulse Dispersion Measurement Results

The pulse dispersion on all fibers in the six designs performed very well, with all values less than the 2.0 ns/km

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Table B.1. Attenuation Measurement Results

Attenuation Before Cabling*
(dB/km)

Cable Design	Design	Max	Min	Avg
Uniroyal Roylar [®] E9-B 2.0" Lay Length	1	4.20	3.71	3.84
Uniroyal Roylar [®] E9-B 2.5" Lay Length	2	3.95	3.54	3.76
Uniroyal Roylar [®] E9-B 3.0" Lay Length	3	4.16	3.43	3.78
B. F. Goodrich 58300 3.0" Lay Length	4	3.86	3.46	3.70
Upjohn 2103-80WC 3.0" Lay Length	5	4.26	3.38	3.93
Mobay Texin 985A 3.0" Lay Length	6	4.43	3.47	4.06

Attenuation After Cabling*
(dB/km)

Uniroyal Roylar [®] E9-B 2.0" Lay Length	1	4.81	4.02	4.42
Uniroyal Roylar [®] E9-B 2.5" Lay Length	2	4.27	3.68	3.99
Uniroyal Roylar [®] E9-B 3.0" Lay Length	3	5.98	3.43	3.78
B. F. Goodrich 58300 3.0" Lay Length	4	7.25	4.60	5.93
Upjohn 2103-80WC 3.0" Lay Length	5	6.00	4.42	5.24
Mobay Texin 985A 3.0" Lay Length	6	5.91	3.86	5.11

*Measured at 0.82 μ m wavelength, 0.089 Injection NA

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Table B.2. Pulse Dispersion Measurement Results

Cable Design	Design	Pulse Dispersion (ns/km)*		
		Max	Min	Avg
Uniroyal Roylar [®] E9-B 2.0" Lay Length	1	1.12	0.38	0.76
Uniroyal Roylar [®] E9-B 2.5" Lay Length	2	2.01	0.50	0.87
Uniroyal Roylar [®] E9-B 3.0 Lay Length	3	0.62	0.53	0.56
B. F. Goodrich 58300 3.0" Lay Length	4	0.60	0.20	0.36
Upjohn 2103-80WC 3.0" Lay Length	5	1.45	0.39	0.61
Mobay Texin 985A 3.0" Lay Length	6	1.35	0.30	0.55

*Pulse dispersion measurement accuracy below 0.5 ns/km can vary because of fiber length and input pulse width.

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requirements (see Table B-2), except for the one fiber indicating 2.01 ns/km.

The pulse dispersion values on most of the fibers were equal to the input pulse width because of the cable length and quality of fibers.

B1.3 Numerical Aperture Measurement Results

The 90% power NA was measured on the finished cables. The results of the data are summarized in Table B.3. The data indicates that the fibers used in the lay length evaluation samples were close to the required 0.20 NA, and that the fibers in the polyurethane evaluation samples all exceed the required 90% power NA value of 0.20. This improvement in NA is the effect of better fiber diameter fluctuation control and a minor change in the graded index fiber profile during the deposition process.

B1.4 Impact Testing Results

The impact testing was conducted in accordance with

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Table B.3. Numerical Aperture Measurement Results.

Cable Design	Design	<u>90° Power NA</u>		AVG
		Max	Min	
Uniroyal Roylar [®] E9-B 2.0" Lay Length	1	.22	.18	.20
Uniroyal Roylar [®] E9-B 2.5" Lay Length	2	.20	.19	.19
Uniroyal Roylar [®] E9-B 3.0 Lay Length	3	.21	.20	.20
B. F. Goodrich 58300 3.0" Lay Length	4	.22	.20	.21
Upjohn 2103-80WC 3.0" Lay Length	5	.22	.20	.21
Mobay Texin 985A 3.0" Lay Length	6	.22	.20	.20

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MIL-C-13777F at room temperature, $+71^{\circ}\text{C}$ ($+160^{\circ}\text{F}$), and at -54°C (-65°F). The lay length evaluation samples exhibited only one failure at room temperature on the 5.1 cm (2.0") lay length cable. The results indicate that changing the lay length to 7.6 cm (3.0") does not affect the impact resistance. The polyurethane evaluation samples had fiber failures and jacket splitting with B. F. Goodrich 58500 having the poorest performance and Mobay Texin 985A and Uniroyal Roylar E9-B showing the best performance.

Uniroyal Roylar E9-B was selected for the final optimized engineering Phase III samples because of its performance and the fact that the Mobay Texin 985A has problems with adhering to itself on the reel causing manufacturing difficulty.

B1.5 Twist Test Results

The twist testing was conducted in accordance with MIL-C-13777F at room temperature, $+71^{\circ}\text{C}$ ($+160^{\circ}\text{F}$), and at -54°C (-65°F). All testing of the six-cable designs was completed without any failures.

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B1.6 Bend Testing Results

The bend testing was conducted in accordance with MIL-C-13777F at room temperature $+71^{\circ}\text{C}$ ($+160^{\circ}\text{F}$) and at -54°C (-65°F). All testing of the six-cable designs was completed without any jacket splitting, but the B. F. Goodrich 58300 sample had two fiber failures at $+71^{\circ}\text{C}$ ($+160^{\circ}\text{F}$) and the Upjohn 2103-80WC sample had one fiber failure at -54°C (-65°F).

B1.7 Tensile Load Testing Results

The cables were subjected to a static tensile load of 181.44 kg (400 lb) over a gage length of 6 meters for 1 minute. All testing was completed on this group without any fiber failures or degradation.

B1.8 Cold Bend Testing Results

The cold bend testing was conducted in accordance with MIL-C-13777F at -54°C (-65°F) around a 31.75 mm od mandrel (5x) for 1 cycle.

The data results indicate no fiber degradation or cracking of the jacket when examined visually under 5x magnification.

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B1.9 Fungus Testing Results

The fungus testing was conducted in accordance with MIL-STD-810B, Method 508.1, Procedural. At the end of the test period the samples were removed and examined for fungus growth. A very light growth was observed on the surface of each sample, however, this growth did not affect the jacket integrity.

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